A digital watermark algorithm based on DCT and improved Watson perceptual model

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Abstract—**An adaptive image watermarking algorithm is proposed based on block Discrete Cosine Transformation(DCT) and the improved perceptual model of Human Visual system(HVS).At first, the digital watermark is transformed by Arnold, then it is effective to make full use of the improved perceptual model in DCT domain and the feature of the subblock luminance to control the strength of the watermark embedded.However, the method can perfect the fidelity of the host image and the robustness of digital watermark. Simulation results demonstrate that the algorithm of watermarking system make a great balance between transparency and robustness, which has a certain practical value.**

Keywords-digital watermark; DCT; HVS; the improved perceptual model; JND

I. INTRODUCTION

With the rapid growth of computer network technology and multimedia processing technology, it is an urgent problem to protect for multimedia information. Digital watermarking is an important method for copyright protection, so how to implement an effective network of copyright has been a great hot spot. Besides, it has a great progress at present.

From the view point of watermark embedding position, digital image watermarking algorithm is usually achieved in time domain or transform domain. At first, the research of digital watermarking is based on time domain. However, we take into account for visual invisibility, and the watermark is often embedded in the least important pixels. Though it is a simple algorithm, it has the poor ability of resisting geometric distortion or noise and the capacity of watermarks to be embedded is quite small. While in transform domain, we firstly transform the image into frequency domain, and then change the coefficients of the frequency domain. Finally, inverse transformation is applied. The most common kinds of transform are DFT, DCT [1, 11], DWT and so on [6].

This paper focuses on the algorithm of DCT transformation on the basis of fully considering HVS characteristics, and the algorithm based on blocked DCT transformation is quite common. Because the payload of the computation is quite small, it is compatible with the standards of international popular data compression (i.e. JPEG,MPEG,H261/263.etc).Besides, the algorithm is easy to achieve in the compressed domain. Owning to its high robustness, the research of digital watermarking based on the binary value in DCT domain has already been deepened.

II. DCT TRANSFORM AND THE ANALYSIS OF COEFFICIENTS

Discrete Cosine Transform (DCT) [3, 5] is applied widely in digital image processing area, and is a kind of orthogonal transformation. It comes from the cosine part of the DFT transformation, so it is a real transformation. Therefore, it is good at energy compression and decorrelation and is compatible with video compression standard. In particular, digital watermarking algorithm on the basis of the model of the image's JPEG compression standard can improve the ability of resisting JPEG compression. Consequently, DCT has attracted much attention in the digital watermarking technology.

Two-dimensional (2D) DCT transform is adopted by most image processing. Assuming image $f(x, y)$ is $N \times N$ matrix, its DCT transformation is defined as:

$$F(u,v)=\alpha_u\alpha_v\sum_{i=0}^{N-1}\sum_{j=0}^{N-1}f(i,j)\cos[\frac{(2i+1)u\pi}{2N}]\cos[\frac{(2j+1)v\pi}{2N}]$$

(1)

Correspondingly, DCT inverse transformation is defined as:

$$f(i,j)=\sum_{u=0}^{N-1}\sum_{v=0}^{N-1}\alpha_u\alpha_vF(u,v)\cos[\frac{(2i+1)u\pi}{2N}]\cos[\frac{(2j+1)v\pi}{2N}]$$

(2)

Where α_u, α_v is defined as:

$$\alpha_u,\alpha_v=\sqrt{\frac{1}{N}},u=0,v=0 \quad \alpha_u,\alpha_v=\sqrt{\frac{2}{N}},u=,v=1,2,...,N-1$$

As mentioned above, while u=0 and v=0 in formula (1), the coefficient of DCT is known as DC coefficient, and other coefficient is AC coefficients. Two-dimensional (2D) DCT transform can not only make the natural image of the main information concentrate on a small amount of low frequency coefficients, but also cause the minimum of the image blocking effect. In the light of most of image processing, we retain important visual components of the image (i.e. images of the main content), while we mainly change other components of the image (i.e. some details of the image); in corresponding transform domain, the important visual components of the image mainly concentrate on the low frequency part of the image spectrum, while some of the details of the image are mainly distributed in the middle and high frequency of the image

spectrum. Therefore, the general processing on the image has small effect on the low frequency component, but it has great influence on the high fluency on high component.

To improve the robustness of the digital watermark,cox and so on[4] proposed that the watermark was embedded into the most important components of human visual system(that is, the coefficients of the low frequency domain).It is possible to cause obvious block effect by changing the coefficient of DC to embed the watermark. Generally speaking, it can't embed the watermark into the coefficient of DC.Therefore, this paper proposes that the embedding positions of the watermark are the component of the middle frequency.

III. ARNOLD TRANSFORM

In this paper, the chaotic map is used to encrypt watermark signal, and it become an important mean for digital image transmission and storage. Arnold cat map is employed to shuffle the embedding positions of pixels in host image, which ensures the security of our scheme.

Scrambling transformation has two prominent characteristics: 1) Scrambling transformations are generally periodic .When the chaotic map iterates a certain number of times, it can return to the original map.2) After scrambling transformation, the size of the map don't change. Arnold scrambling (cat mapping) is a transformation that V.J.Arnold[10] presented in ergodic theory research, which is a kind of traditional chaotic system. It is defined as follows:

$$\begin{pmatrix} x^{'} \\ y' \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} (\mod N)$$
$$x, y \in \{0,1,2...,N-1\}$$

Where N denotes the order number (i.e. the size of the map, usually considering square images),$\begin{pmatrix} x \\ y \end{pmatrix}$denotes the position of the pixels before Scrambling transformation,$\begin{pmatrix} x' \\ y' \end{pmatrix}$denotes the position of the pixels after scrambling transformation.

IV.THE IMPROVED WATSON'S PERCEPTUAL MODEL

According to the difference of each person, human visual system[7] is also different from the sensitive level of the image. Owing to the invisibility of digital watermark, it's requisite to establish the system of the good HVS model [8].At the same time, we must make a large number of experiments. In the procedure of graphical coding, we make full use of the effect of the human masking so as to embed into much more information. Human visual system (HVS) [9] has such characteristics, which are as follows: 1) Sensitivity to the luminance: in a homogeneous background, human eyes are not sensitive to the quite bright or black regions; 2) Contrast masking: in the regions with strong contrast, such as the edge regions, human eyes have a high visual threshold; 3) Textures masking: in the regions with complicated textures, human eyes have a higher visual threshold than that in the flat regions. The sensitivity to the luminance can be measured by the gray values. The regions

in host images with strong or weak gray values can be embedded with strong watermarking. The density of edge pixels can measure the contrast and a texture, i.e.

the higher density demonstrates the higher contrast and more complicated textures.

JND[12](Just Noticeable Difference) is the very important concept of perceptual model, which is the threshold of the changed signal. While embedding into the watermark, we must meet the demand that the embedded strength of each pixel can't exceed one unit of JND.In the year of 1993, Watson A B [2] proposed the visual model based on DCT and the concept of JND.The perceptual model consists of sensitivity, luminance masking, contrast masking, and a pooling. As for the coefficients of DCT transform, Human visual system (HVS) has three characteristics: contrast sensitivity (TC), luminance sensitivity (TL), frequency sensitivity (TF):

$$t_L[i,j,k] = t(i,j)(C_0[0,0,K]/C_{0,0})^{\alpha T} \quad (3)$$

where αT is a constant ,wherein they suggest a value of 0.649, $C_0[0,0,k]$ is DC coefficient of the kth block in the original image, $C_{0,0}$ is an average of the DC terms for the complete image. And t [i, j] is the sensitivity table that is defined by Watson perceptual model, which reflect human eye sensitivity of different frequency.

$$s[i,j,k] = \max\{t_L[i,j,k],|C_0[i,j,k]|^{w[i,j]} t_L[i,j,k]^{1-w(i,j)}\} \quad (4)$$

Where $w[i,j]$ is a constant between 0 and 1, which is different from the coefficient of the frequency, but a typical empirical value, is 0.7.But in the improved model

$$s[i,j,k] = \min\{t_L[i,j,k],C_0[i,j,k]^{w[i,j]} t_L[i,j,k]^{1-w[i,j]}\} \quad (5)$$

Where αT is 0.849, and $w[i,j]$ is 0.01.

V. WATERMARK EMBEDDING

During the procedure of watermark embedding, we apply a kind of technique on the basis of the middle frequencies of DCT.According to the research of HVS,we found that human eyes are more sensitive to the low frequency part of the nosies.To improve the invisibility of digital watermark, we can embed the watermark into the high frequency part of the host image, but it is easy to miss the information of digital watermark by quantification, low pass filtering and so on.Thus,the means of embedding watermark have a negative effect on the robustness of the watermark.Consequently,it is a tradeoff between robustness and invisibility to choose the middle frequency part of the host image.

0	1	5	6	14	15	27	28
2	4	7	13	16	26	29	42
3	8	12	17	25	30	41	43
9	11	18	24	31	40	44	53
10	19	23	32	39	45	52	54
20	22	33	38	46	51	55	60
21	34	37	47	50	56	59	61
35	36	48	49	57	58	62	63

8×8zig-zag order

The positions of the original image are the part of the matrix in which the position of the value is 1, the matrix is as follows:

midband= [
0, 0, 0, 0, 0, 0, 0, 0;
0, 0, 0, 0, 0, 0, 0, 0;
0, 0, 0, 0, 0, 0, 0, 0;
0, 0, 0, 1, 1, 0, 0, 0;
0, 0, 0, 1, 1, 0, 0, 0;
0, 0, 0, 0, 0, 0, 0, 0;
0, 0, 0, 0, 0, 0, 0, 0;
0, 0, 0, 0, 0, 0, 0, 0];

The step of embedding algorithm is as follows:

(1)The binary watermark image is transformed into M' by Arnold transformation to lower the autocorrelation coefficients of the image, and retain the key K.

(2)The host image $f(x, y)$ that its size is N×N is divided into 8×8 blocks block(x,y)(x,y=1,2,...8).According to the improved Watson's perceptual model, we can gain the JND matrix of each block (that is, ths matrix).

(3)The original image is partitioned into non-overlapping blocks, and block_dct(x,y)is getted after block(x,y)is transformed into DCT domain.

(4)Let us read the scrambling binary image M', if $M'(i, j)$=0, then a=1, otherwise a= -1.According to the location of the embedded pixels that the value in matrix called midband is 1, we change the coefficients of the host image, the formula is given by:

block_dct(j,i)=block_dct(j,i)*(1+a(j,i)*ths(j,i);

(5)After block_dct(j,i) is modified, watermarking image is achieved when inverse DCT transformation is applied in each block.

(6)Merging the image of each block, we can get the watermark embedded image I_W.In addition, we make public the embedded locations of the matrix called midband.

VI. WATERMARK EXTRACTION

(1)The watermark embedded image I_W and the host image are divided into 8×8 non-overlapping blocks,respectively.Then, we transform them into DCT domain (i.e. block_dct1 and block_dct).

(2)According to the positions of the embedded watermarking image, we employ this formula. The formula is given by:

aa=block_dct1/block_dct-1

If aa>=0, $w'(i)$=1,otherwise $w'(i)$=0;

(3)After we deal with the watermark embedded image of each block, we obtain the scrambling watermark image W'.According to the key K, the watermark signal is achieved after W' is transformed by Arnold.

VII. SIMULATION RESULTS

The simulations are performed in Matlab.Peak signal to noise ratio (PSNR)[6] is used to measure the invisibility of the embedded watermark and normalized cross correlation (NC) is used to measure the similarity between the extracted watermark and the original watermark. The formulas are given by:

$$PSNR = 10 \log_{10} \frac{MN \max[\max(I^2)]}{\sum_{i=1}^{i=M} \sum_{j=1}^{j=N} [I(i, j) - I'(i, j)]^2}$$

Where I is the host image, I' is the image embed with watermark,M×N is the size of I.

$$NC = \frac{\sum_{i=1}^{i=M} \sum_{j=N}^{j=M} W(i, j)W'(i, j)}{\sum_{i=1}^{i=M} \sum_{j=1}^{j=M} W(i, j)^2}$$

Where W denotes the original watermark, W' denotes the extracted watermark.

One 256×256 gray images 'Lena' is used for testing in Figure 1(a), and a size of 32×32 binary image shown in Figure 1(b) is selected as watermark.

(a) Host image   (b) Original watermark

Figure1 Gray carrier image and watermark image

(c)Image embedded (d) Watermark extracted
With watermark under normal environment

Figure 2 Image embedded with watermark and watermark extracted under normal environment.

When the watermark is extracted under normal environment, NC=1 and PSNR=64db. To test the robustness of the algorithm, a sequence of attack experiments with different level of strength are applied to the image embedded with watermark .The attack experiments are as follows:

(1)JPEG compression

Quality factor	NC	PSNR
80%	0.9997	45.3672
60%	0.9994	44.7452
40%	0.9993	44.6219
10%	0.9989	42.8051

(2)Filtering

The kind of filter	NC	PSNR
Median filter	0.9991	42.9963
Gaussian	0.9986	41.8547

(3)noise contamination

The kind of noise	NC	PSNR
Gaussian noise	0.9946	49.4689
Salt & Pepper noise	0.9948	44.5986

The watermarks extracted from the watermarking images which are contaminated by Gaussian noise whose average value is 0 and variance is 0.001, and Salt & Pepper noise whose strength is 0.01.If we comply with the rules

that NC≥0.750, we can obtain an effective watermark.

(4)Image cropping

The percentage of the image cropping	NC	PSNR
1/4	0.9989	43.2751
1/2	0.9978	42.4931

VIII. CONCLUSION

An improved Watson's perceptual model image watermarking has been introduced in this paper. The paper proposes an adaptive robust watermarking algorithm in DCT domain associating with scrambling technology, HVS and DCT transform. The watermark is embedded into a digital image, by modifying the middle frequency coefficients in DCT domain .In spite of the method's simplicity, the embedded watermark can successfully survive after attacked a series of image processing operations. At the same time, we can get a compromise between transparency, robustness and capacity.

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